iEMSs International Congress on Environmental Modelling and Software

10th International Congress on Environmental Modelling and Software
Brussels, Belgium, Ann van Griensven, Jiri Nossent, Daniel P. Ames (Eds.)
https://scholarsarchive.byu.edu/iemssconference/2020/

A new framework to reduce uncertainty in Wellhead Protection Area prediction using Bayesian Evidential Learning

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Abstract: Decisions related to groundwater management such as sustainable extraction of drinking water or protection against contamination can have great socioeconomic impacts. Ideally, a complete uncertainty analysis should be performed to assess risk and foresee all outcomes of any prediction. Uncertainties stem from the intricacy of the subsurface physical properties and the scarcity of data, measuring directly or indirectly the parameters of interest, relying on our limited understanding of the physical processes at stake. In this contribution, we compute the wellhead protection area (WHPA), whose shape and extent is influenced by the hydraulic conductivity (K) distribution, from tracing experiments. We predict WHPA within the Bayesian Evidential Learning framework, which aims at finding a direct relationship between data (d, tracing experiments) and forecast (f, WHPA) using machine learning. Given n different K fields describing n unconfined aquifer models with one pumping well, $2n$ forward models are computed to generate n samples of d and f. Both their dimensions are reduced using Principal Component Analysis, and a relationship between the two is sought using Canonical Correlation Analysis, allowing us to infer the mean and posterior covariance of the prediction in reduced space. Drawing m random samples from this multivariate normal distribution and back-transforming them in the original physical space generates m posterior WHPA to quantify the range of uncertainty in the prediction. This range is affected by the number and position of tracer wells. The aim is then to optimize the design of those wells to reduce the uncertainty. Increasing the number of injecting wells within the WHPA effectively does so, as the breakthrough curves will store information on a larger portion of the K field surrounding the pumping well. Experimental design prior to field investigation as proposed in our approach helps to identify the optimal location of wells, within limited budget constraints.

***Keywords**:* Groundwater modeling; Bayesian Evidential Learning; Experimental Design; Machine Learning